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Short communication

Compressive properties and damping capacities of magnesium reinforced with continuous steel wire

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ABSTRACT

The magnesium reinforced with continuous 304 stainless steel wire (304/Mg) was fabricated using an infiltration casting process. The 304/Mg has a novel internal structure. The compressive properties and damping properties of 304/Mg were tested. The stress-strain curve of 304/Mg was similar to that of metal rubber. The compressive strength and elastic modulus of 304/Mg were 42.8% and 55.6% higher than those of pure Mg, respectively. The energy absorption capability of 304/Mg was 2.5 times as high as that of pure Mg. Dynamic mechanical analysis (DMA) tests indicated that the damping capacity of pure Mg was higher than that of 304/Mg at low strain amplitude. Two internal friction peaks (P1 and P2) presented in the temperature-dependent damping curve. The P1 peak of 304/Mg shifted to lower temperature and P2 peak shifted to higher temperature compared to those of pure Mg. The preparation method of 304/Mg composite can be a reference to improve the damping capacity and strength of Mg.

1. Introduction

The loss caused by vibration and noise has attracted a lot of attention [1–3]. Research and development of high damping materials is an effective means of reducing vibration and noise [4–6]. Therefore, an increasing number of researchers devote themselves to high damping materials [7–10]. Magnesium has drawn considerable attention due to its low density, high specific strength and good damping capacity [11–13]. Nonetheless, the low strength of magnesium limits its application [14]. Alloying treatment and compositing treatment are two ways to improve the strength of magnesium, but at the expense of damping capacity [15–19]. Therefore, improving the strength and the damping capacity of magnesium at the same time is significant.

In this paper, a novel 304/Mg composite was fabricated. The compressive properties and damping capacities of 304/Mg were tested. The results showed that 304/Mg has higher strength and energy absorption capability than those of pure Mg. Moreover, the damping capacity of 304/Mg remained the same level as pure Mg. Therefore, this 304/Mg can be a promising candidate for anti-vibration and noise-reduction structure components.

2. Materials and methods

A 304 stainless steel wire (0.20 mm in diameter) and a commercial pure Mg ingot (99.9% purity) were used as raw materials. The 304 stainless steel wire was firstly wound into a spiral-shape, and then stretched and woven into a 2D mesh. The mesh was rolled into 3D material and pressed in mould to form cylindrical p-304 preform. The 304/Mg composite was fabricated by infiltration casting. The Mg was melted and kept at 700 °C under the protective atmosphere of SF_6 and CO_2 mixture. The as-prepared p-304 preform was preheated to 350 °C, and then soaked in the Mg melt. The p-304 was taken out after being filled with Mg melt and quickly cooled down to room temperature. Thus, the 304/Mg was fabricated.

The volume fractions of 304 stainless steel wire and Mg were controlled by adjusting the mass of 304 stainless steel wire. These can be calculated by the following formulas:

$$m_{304}=V\times\psi_{304}\times\rho_{304} \quad (1)$$

$$\psi_{Mg}=1-\psi_{304} \quad (2)$$

where m_{304} is the mass of 304 stainless steel wire, V is the volume of sample, ψ_{304} is the volume fraction of 304 stainless steel wire, ρ_{304} is the density of 304 stainless steel wire and ψ_{Mg} is the volume fraction of Mg.

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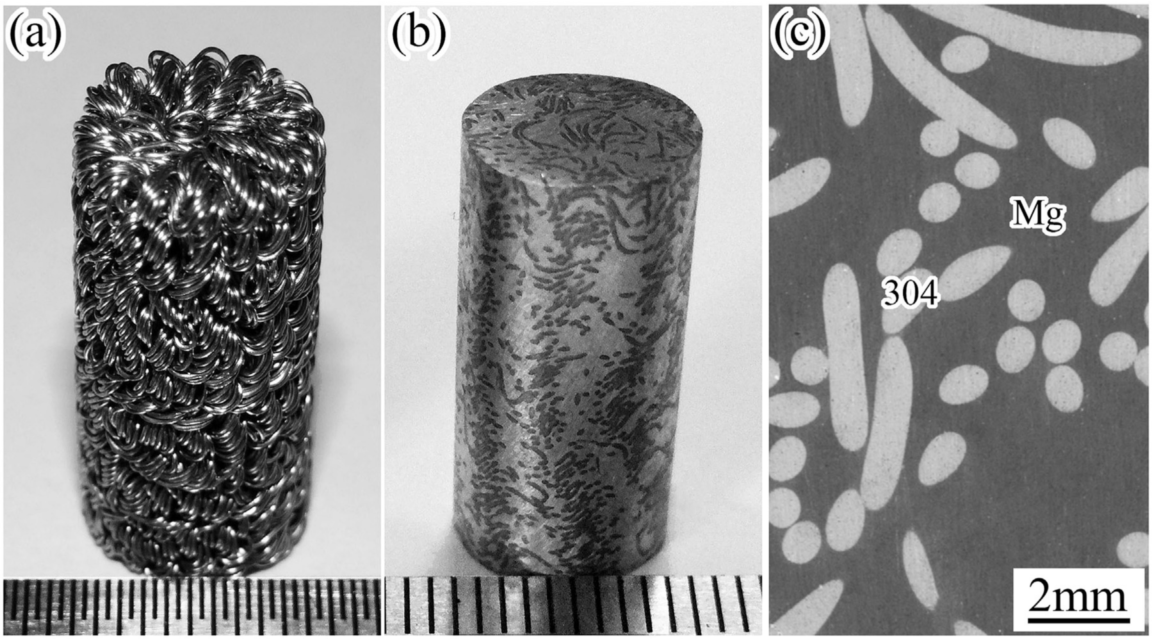

Fig. 1. Macrographs of p-304 (a) and 304/Mg (b) and cross section image of 304/Mg(c).

In this study, the porosity of p-304 preform was controlled to about 70%. Thus the volume fractions of 304 stainless steel wire and Mg in 304/Mg composite were 30% and 70%, respectively. For compression tests and dynamic mechanical analysis (DMA) tests, 304/Mg specimens with dimensions of Ø10 mm×20 mm and 20 mm×5 mm×1 mm were prepared, respectively.

The compressive strengths of pure Mg, p-304 and 304/Mg were conducted on ZWICK AG-100 kN testing machine. The tests were conducted at the crosshead speed of 1 mm/min. Three samples were tested for each group. The average of three measurements was taken as the report value.

The elastic moduli of pure Mg, p-304 and 304/Mg can be calculated by the following equation:

$$E=\sigma/\varepsilon \tag{3}$$

where σ is the engineering stress and ε is the engineering strain.

Considering the test machine compliance, the tested mechanical properties should be calibrated by subtracting the compliance that could be determined by comparing the difference between the measured and theoretical load-displacement relationships for the known pure Mg (its elastic modulus is 45 GPa). This method, suggested by Kalidindi et al. [20] based on the assumption that the loading system was linear elastic in the loading range during testing, was used to calibrate all the elastic modulus of the materials in this study.

The energy absorption capabilities of pure Mg, p-304 and 304/Mg can be calculated by the following equation [21,22]:

$$E=\int_0^{\varepsilon}\sigma d\varepsilon \tag{4}$$

where E is the energy absorption capability, σ is the stress and ε is the strain.

The damping capacities of pure Mg and 304/Mg were measured on a Dynamic Mechanical Analyzer (DMA8000) with single-cantilever mode at room temperature. The strain range was set from 2×10^{-5} to 2×10^{-3} at a frequency of 1 Hz. The resulting sinusoidal force and deflection data were recorded. The damping capacities can be evaluated by the loss tangent (tanθ) calculated by the following equation [23]:

$$tan\theta=E''/E' \tag{5}$$

Where E'' is the loss modulus and E' is the storage modulus.

The temperature-dependent damping was measured from room temperature to 450 °C at different frequencies. The heating rate was set to be 5 °C/min, and the strain amplitude was set to be 2×10^{-4}.

3. Results and discussion

3.1. Morphological characterization

The macrographs of p-304 and 304/Mg were shown in Fig. 1. Magnesium melt filled into the pores of p-304 to form the 304/Mg composite. The 304 stainless steel wire was the strengthening phase of 304/Mg composite. The 304 stainless steel wire in 304/Mg composite kept continuous, which was different from dispersed particles or fibers in Mg matrix composites that have been reported elsewhere [24,25]. This novel internal structure might result in unusual properties.

3.2. Compressive properties

The stress-strain curves of pure Mg, p-304 and 304/Mg were shown in Fig. 2. The p-304 has a typical stress-strain curve of metal rubber. It could be divided into three stages, an initial elastic stage followed by an initial plateau stage, and then a densification stage. The stress-strain curve of 304/Mg was similar to that of p-304, indicated that the 304/Mg has some properties of porous materials. The compressive strengths and elastic moduli of pure Mg, p-304 and 304/Mg were shown in Fig. 3. The compressive strengths of p-304, pure Mg and 304/Mg were 5 ± 1.0 MPa, 140 ± 20.0 MPa and 200 ± 25.0 MPa, respectively. The elastic moduli of p-304, pure Mg and 304/Mg were 1 ± 0.2 GPa, 45 ± 5.0 GPa and 70 ± 10.0 GPa, respectively. The compressive strength of 304/Mg was 42.8% higher than that of pure Mg, and the elastic modulus was 55.6% higher than that of pure Mg. Thus, this 304/Mg composite has higher strength than pure Mg and has some properties of porous materials at the same time.

According to Kelvin-Voigt model, the elastic moduli of two phase composite materials can be calculated by the following formula [26]:

$$E_C=E_1V_1+E_2V_2 \tag{6}$$

Where E_c is the complex modulus, E_1 and E_2 are the elastic moduli of phase 1 and phase 2; V_1 and V_2 are the volume fractions of phase 1 and phase 2.

The elastic moduli of 304 stainless steel and pure Mg are 195 GPa